QUANTUM PHASE TRANSITIONS

Summer 26
Lukas Janssen

Coordinates

Mo 9:20 – 10:50 BZW/A120
Fr 9:20 – 10:50 BZW/A120

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Website: http://tu-dresden.de/physik/qcm/lehre/qpt-ss26

Exam: oral exam as part of rigorosum/replacement (PhD students) or specialization "Theoretical physics" (MSc students) possible

Exam prerequisite (PVL, MSc students): written problem solutions, > 1/3 of points, presented in class

Ungraded assessment (PL, BSc students): written problem solutions, > 1/3 of points, presented in class

Content

1 Introduction

<u>Phase</u> (a definition attempt): Equilibrium state of matter whose qualitative characteristics do not change upon small change of external parameters ("stable")

$\Rightarrow$ thermodynamic potential varies <u>analytically</u>

Phases are:

- characterized by <u>symmetry</u> of $\rho = \sum_j p_j |\psi_j\rangle\langle\psi_j|$ (density operator)
- separated by <u>phase transitions</u>

<u>Phase transition</u>: Point in parameter space at which equilibrium properties of a system change qualitatively ("unstable")

$\Rightarrow$ thermodynamic potential <u>nonanalytic</u>

Phase transitions can:

- be <u>continuous</u> or <u>discontinuous</u>
- occur at $T > 0$ ("<u>thermal</u>") or $T = 0$ ("<u>quantum</u>")

<u>Quantum phase transition (QPT)</u>: Phase transition at <u>$T = 0$</u>, which occurs upon varying non-thermal control parameter (pressure, magnetic field, chemical composition, ...)

$\Rightarrow$ ground-state energy <u>nonanalytic</u> in control parameters

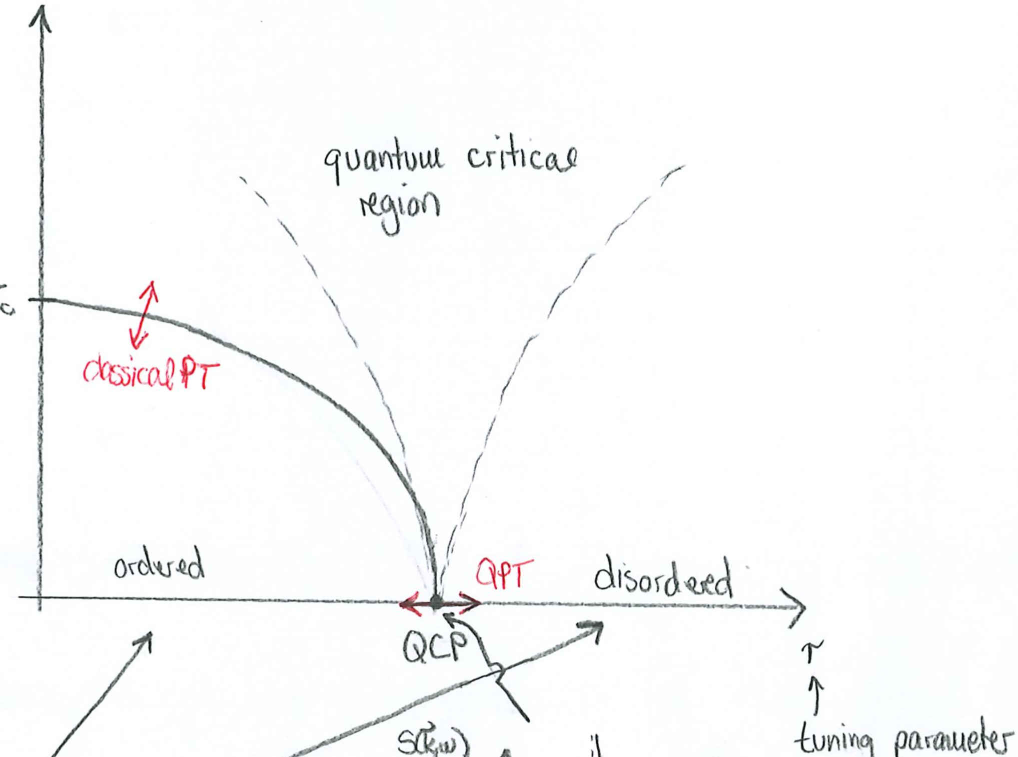
<u>Remark</u>: QPT apparently driven by "quantum fluctuations"

Disclaimer: $T = 0 \Rightarrow$ state described by single phase-coherent (many-body) wavefunction

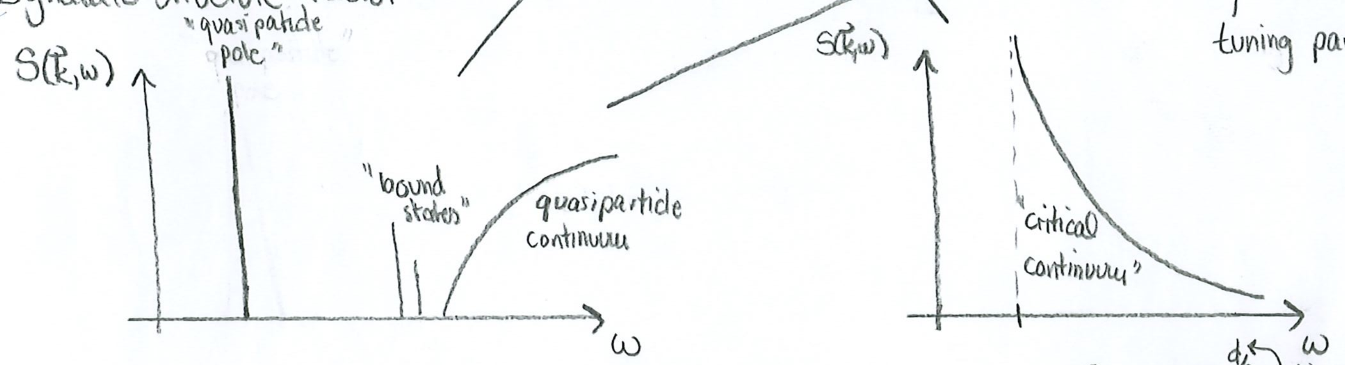
"fluctuations": deviations from a reference state (e.g., ordered magnet)

Experimental relevance:

Quantum phase diagram:



Dynamic structure factor:



e.g., Fermi liquid : $C_V \sim T$

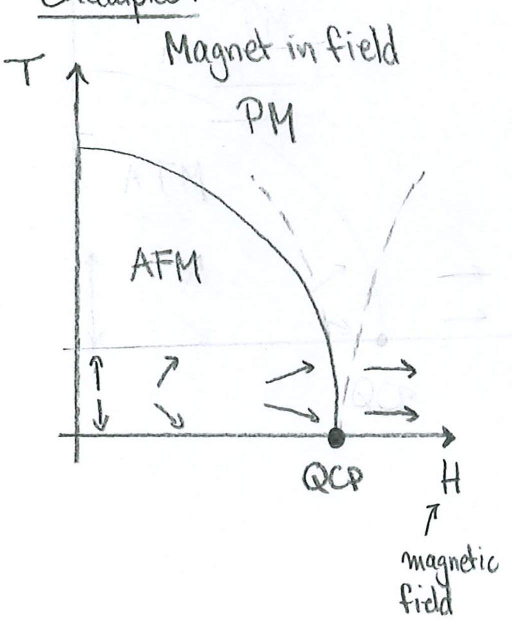
gapped magnet : $C_V \sim \frac{1}{T} e^{-\frac{\Delta}{k_B T}}$ ← gap

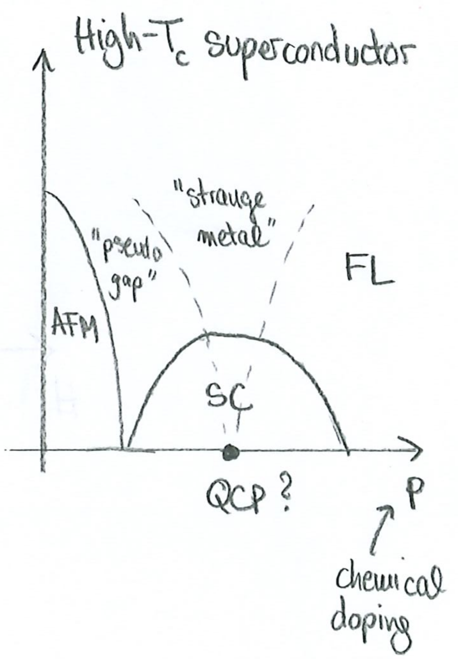
e.g., $C_V \sim T^{d/z}$ ← dimension

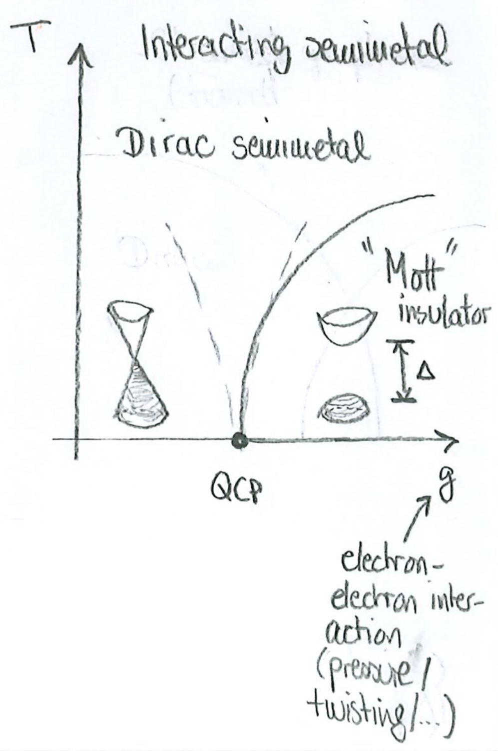
↑ "dynamical critical exponent"

"novel state of matter"

Examples:







Other examples:

- disordered system ("Anderson transition")
- cold atoms on an optical lattice
- quark matter ("chiral symmetry breaking" in QCD)

13.4.26